Repair of Coral Reefs Following Large Vessel Groundings

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I. INTRODUCTION

Between 1997 and 2002, the National Oceanic and Atmospheric Administration (NOAA), National Marine Sanctuaries Division, conducted three major coral reef repairs. The repairs were conducted in response to large vessel groundings on coral reefs. The purpose of the repairs was to mitigate for biological damage and to repair reef structure. Two of the repairs were conducted in the Florida Keys, and one repair at Mona Island, Puerto Rico. In chronological order, the three reef repairs are described as follows:

II. 1997 MONA ISLAND, PUERTO RICO CORAL REEF RESTORATION

A. Mona Island

Mona Island is located about halfway between Puerto Rico and the Dominican Republic. The island is about 14 square miles in size, with cliffs on all sides. A fringing coral reef exists along the southern and western sides of the island.

B. Damage Incident

In July of 1997, the *Fortuna Reefer*, a 325-foot container ship, grounded on the fringing coral reef of Mona Island, Puerto Rico. The grounding occurred in an area dominated by a well-established thick of elkhorn coral, *Acropora palmata*, within an approximate 7-acre grounding site. The grounding resulted in fracture of numerous elkhorn coral colonies, shattering the colonies and scattering fragments around the grounding impact area. The grounding occurred in an area frequently subject to large swells. As a result, most of the fragments of the elkhorn coral colonies were swept off of the hardbottom into areas of sand, preventing the opportunity for re-establishment of the coral.

C. Repair Plan

After conducting a site inspection, NOAA reef restoration biologists determined that retrieving viable fragments of the coral and stabilizing them on the hardbottom might expedite the recovery of the *Acropora palmata* community. Additionally, it was apparent that the condition of the coral fragments, as would be expected, was deteriorating. As a result, the restoration effort was considered an emergency to be accomplished as soon as possible. Further, it was determined that several methods of stabilization would be attempted to develop the best approach. The government wished to stabilize at least 400 pieces of the corals on the reef. Coastal Planning & Engineering, Inc. of Boca Raton, Florida was retained by NOAA as the contractor to conduct the reef restoration.

D. The Restoration Effort

Mona Island is located halfway between Puerto Rico and the Dominican Republic, and is relatively isolated. Human habitation of the island was limited to a number of park rangers. In order to conduct the restoration effort, living quarters were required to house the divers and biologists conducting the restoration effort. In response to this requirement, a live-aboard dive vessel was chartered for a month to stay onsite, providing living quarters and logistical support. In addition to the live-aboard dive boat, several local vessels from western Puerto Rico were chartered to ferry food and supplies back and forth between Puerto Rico and Mona Island, and to provide a platform from which to work. The live-aboard dive vessel could not be utilized as a work platform for the reef repair effort because the reef repair site was subject to large swells, and there was additional concern related to anchoring in the active wave zone. Rather, the live-aboard vessel was anchored off Mona Island in an area which provided a level of protection from waves. Small vessels were utilized to ferry divers back and forth to the reef repair site.

Report Documentation Page

Form Approved
OMB No. 0704-0188

1. REPORT DATE	2. REPORT TYPE	3. DATES COVERED
01 SEP 2003	**N/A**	**-**

4. TITLE AND SUBTITLE	5a. CONTRACT NUMBER
Repair of Coral Reefs Following Large Vessel Groundings	5b. GRANT NUMBER
	5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S)	5d. PROJECT NUMBER
	5e. TASK NUMBER
	5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **Coastal Planning & Engineering, Inc. 2481 N.W. Boca Raton Boulevard Boca Raton, Florida 33431, USA**	8. PERFORMING ORGANIZATION REPORT NUMBER
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)	10. SPONSOR/MONITOR'S ACRONYM(S)
	11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release, distribution unlimited

13. SUPPLEMENTARY NOTES
See also ADM002146. Oceans 2003 MTS/IEEE Conference, held in San Diego, California on September 22-26, 2003. U.S. Government or Federal Purpose Rights License

14. ABSTRACT

15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT	b. ABSTRACT	c. THIS PAGE			
unclassified	**unclassified**	**unclassified**	**UU**	**4**	

Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std Z39-18

Upon initial arrival at the site, a survey was conducted to assess the area in terms of numbers of coral fragments scattered about, evaluate the area of impact, and determine where corals could be re-established on the hardbottom without impacting undamaged communities.

After experimentation, it was determined that the best way to stabilize the corals was to wire the corals down to pins established in the reef. The density of the reef material, however, was such that pins could not be driven into the reef without bending the pins. As a result, hydraulic drills were utilized to drill holes in the reef to establish the pins and wire the corals down. Stainless steel pins and wire were utilized to conduct the restoration.

Given the wave climate at the repair site, it was apparent that the swells would be a major consideration in stabilization of the corals. Divers attempting to work on the bottom were affected by swells which would roll them over, creating a very difficult work situation. In order to protect the divers and to provide some degree of stability while on the bottom, divers wore coveralls and excessively heavy weight belts to pin them to the bottom. Nevertheless, in the shallow water portions of the repair area, divers were subject to heavy swell activity which slowed the work effort.

Typically 8 to 9 divers worked on the repair effort. The effort was conducted on a continuous basis (7 days per week) in order to recover as many coral fragments as possible, as quickly as possible. After a few days of work, an efficient work regime was developed with divers specializing in certain tasks (drilling, wiring, collecting corals), which greatly increased the speed of the effort.

The damaged area was subdivided by CPE surveyors in order to ensure each area was completely and thoroughly examined and as many coral fragments as possible gathered and stabilized on the hardbottom. In an effort that took almost one month, 1857 coral fragments were gathered and stabilized, far exceeding the goal of 400 coral fragments. Nevertheless, many of the coral fragments which were gathered showed some degree of stress, with no guarantee that the coral fragment would survive and regrow. Also of concern was the fact that white band disease, which was affecting the elkhorn coral, had been observed within near vicinity of the damaged area. Despite the stressed condition of most of the fragments, many fragments did attach and grow.

III. LOOE KEY CORAL REEF RESTORATION PROJECT (1999)

A. Looe Key

The Looe Key Existing Management Area within the Florida Keys National Marine Sanctuary (LK) is located in the southern Florida Keys, approximately eight miles southwest of Big Pine Key, Florida. Looe Key was designated as a National Marine Sanctuary in 1981, and consists of a five-square mile area of seafloor surrounding the Looe Key reef location. The coral reef of Looe Key is a "spur and groove" reef formation. Each spur consists of a hard outer limestone layer and an interior structure composed of coral skeletal fragments bonded together by a calcium carbonate cementing agent.

Looe Key is a unique reef formation, even when compared to other coral reefs in the Florida Keys. In describing the reef, Clark, Causey, and Bohnsack (1989) wrote that,

> "Looe Key is well recognized as having the most developed "spur-and-groove" reef system in the mid- to lower Florida Keys. This structure is believed to have been formed over a 5,000 to 7,000 year period as the "stepping back" or landward growth of *Acropora palmata* resulted in the high profile (3-5 m) spur-and-groove formation. Looe Key Reef, which is located on the "Florida Reef Tract," is a bank reef community that lies approximately 8.4 km from the nearest point of land. It is the only fully developed bank reef along 44 km between Sombrero Reef off Marathon and American Shoals Reef. The attractiveness and productivity of the reef and the fact that it is the only major bank reef for such a long distance has added tremendously to the level of visitation over the years."

B. Damage Incident

On August 10, 1994, the 155-foot University of Miami research vessel *Columbus Iselin* ran aground on the spur-and-groove coral reef formation in the western portion of Looe Key. Eight areas of damage were identified, including four sites of significant damage. In the four areas of significant damage, the damage consisted of fragmentation of the reef structure and significant loss of reef substrate. The grounding impacted approximately 3,750 square feet of reef area with the loss of an approximate volume of 7,500 cubic feet of reef material (Coastal Planning & Engineering, Multibeam Survey Results, July 1997). The grounding also resulted in the mortality of benthic fauna and displacement of mobile fauna. During a July 1997 site investigation, virtually no benthic invertebrate recovery was observable within the areas of severe damage, most likely due to the lack of stable substrate to support recolonization.

C. Structural Damage

The magnitude of the structural reef damage was further increased due to the impact of Hurricane Georges in 1998. The effect of the hurricane was to scour and excavate additional reef material from the inner reef structure, consisting of coral fragments held together by a cementing agent. The storm's effects resulted in the destabilization of the structure, increasing the surface area of damage and almost doubling the volume of reef material loss. It became

obvious that a structural repair of the reef was required to prevent further degradation of the structure reef, and to restore the habitat provided by the reef spurs. As a result, the focus of the reef restoration effort was to recreate pre-existing habitat structure and surface topographical relief to allow benthic organisms to recolonize the area, and to stabilize each spur and prevent further deterioration.

D. Repair Plan

In general, the repair plan involved the use of limestone boulders placed within the four damage depressions in the reef, stabilized with a tremie pour of concrete around the boulders. The boulders contained in each reef repair area were bound together by concrete to create a single repair unit at each of the four repair sites. The repair depended on the weight of each formed unit to provide structural stability in storm events, with no dependence on the natural reef structure for stability. The sides and surface of each repair included exposed surfaces of the boulders to provide a topography similar to that of the undamaged reef spurs and enhance the opportunities for benthic recolonization of the repair area surfaces.

E. Reef Repair

A total of six contractors bid for the opportunity to repair the reef. The selection process focused on both the qualifications of the individual contractors and the bid price. The personnel and equipment to be used at the site were evaluated in terms of their ability to achieve the goals of the project. Each bid was accompanied with the details of the methodology that each contractor proposed to use to construct the reef repairs. These details were compared to the project specifications to determine which of the contractors best understood the nature of the project, and a contractor was selected.

The repair was constructed in July and August of 1999. Prior to the start of construction, a concrete test pour was conducted to evaluate the performance of the specially-formulated concrete to be used for the underwater tremie-pour. After completing a test pour to observe the concrete performance and placement techniques, the contractor mobilized to the Looe Key site on July 19, 1999. The contractor brought to the site a 160 ft. barge and tug, equipped with a ten cubic yard capacity cement mixer and a 100 ton crane, along with some material to begin construction on the first site. The barge was positioned at the mooring site, extending east and west along four reef spurs just offshore (south) of the damage sites. A minor amount of excavation of loose material from within the damage sites was conducted prior to placing boulders in. The perimeter boulders were initially placed and sealed with chinking stone and mortar. After construction of the repair perimeter, and placement of interior boulders and rebar, the contractor poured the concrete. The concrete material performed well, filling gaps within and between the boulders and the adjacent reef. The final concrete pour was followed by the embedment of surface stone and reef material in the fresh concrete to create a more naturally appearing surface. All four of the repair sites were completed in a similar manner. The project was completed and the contractor departed from Looe Key on August 22.

IV. MOLASSES CORAL REEF RESTORATION PROJECT (2002)

A. Molasses Reef

The Molasses Coral Reef is located in the Upper Keys, approximately 6 nautical miles (11 kilometers) southeast of Key Largo in Monroe County, Florida and within the Key Largo portion of the Florida Keys National Marine Sanctuary. Inshore to offshore, the subaqueous or marine communities of Molasses Reef range from seagrass flats, reef flat (mostly rubble), spur and groove, buttress zone, mixed hardgrounds and sediments, and slope platform**.**

B. Damage Incident

On August 4, 1984, a 400-foot Cypriot registered freighter, the M/V *Wellwood*, ran aground on the upper fore reef of Molasses Reef in about 6 meters of water, damaging the reef. Additional injury occurred to the reef while the vessel was aground for 12 days. The damaged site was situated in a transitional coral community. The grounding injured over 810,000 square feet of reef habitat, including 6955 square feet of coral reef framework (NOAA, 2001a). The injuries ranged from superficial scraping of the reef surface and toppling or crushing of large coral heads, to severe fracture of the reef structure. The grounding caused severe adverse biological and physical impacts to the reef community with widespread mortality of benthic fauna and the displacement of mobile fauna. Additional reef injury occurred as a result of Hurricanes Elena and Kate in 1985 and the active 1998 storm season.

C. Repair Plan

The Molasses reef repair plan was developed in 2001. The philosophy of the repair was to create a site restoration which appeared as natural as possible while providing for repair stability in a major storm event. In general, the repair plan addressed individual damage areas or sites on the reef. The 14 repair sites were repaired through the use of either artificial reef modules constructed by Harold Hudson, Reef Restoration Biologist of the Florida Keys National Marine Sanctuary, or small limestone boulders, both embedded in the undamaged reef structure with tremie pour concrete. Reef module placement was contingent upon embedding the concrete base of the artificial reef module into the natural reef, and locking the module into the reef structure using tremie pour concrete around the module's base. Often, excavation was required to recess and anchor the module in the reef substrate. A total of 9 repair sites received reef modules, while 5 sites were repaired by tremie pour concrete dressed with a limestone rock surface.

D. Construction Contractor Selection

Five contractors from the United States bid for the opportunity to repair the reef. The "Best Value" selection process was used to select the contractor for the project. The contractors bidding on the project were narrowed down to three firms which were considered to be capable of constructing the reef restoration project. The three firms were re-evaluated and two of the three companies were considered most capable. Based on the bid to conduct the work, the contractor was selected.

E. Reef Repair

The reef restoration project was constructed from May through July 2002. Prior to the start of construction, a concrete test pour was conducted to evaluate the performance and placement techniques of the specially-formulated concrete which was used for the underwater tremie-pour. The performance of the concrete was a key element to the success of the repair effort.

After completing a successful test pour, the contractor mobilized to the Wellwood site. The contractor utilized a 120 foot barge, equipped with a 4-cubic yard cement mixer and a 100 ton crane. An aluminum frame outline of the reef module, which was constructed by NOAA, was used underwater to determine the exact location, orientation and accurate leveling of each reef module prior to placement at the repair site.

The contractor began construction on the first individual restoration site on June 1, 2002. The perimeter boulders were placed and sealed with chinking stone and mortar. After construction of the reef perimeter, the reef module was lowered by crane into the repair site and rebar was placed around the module. The concrete pour began once the perimeter and module placement was approved by NOAA personnel and the on-site engineer. The concrete pour was followed by placement of embedding surface stone and reef material into the fresh concrete, creating a natural appearing surface.

The eight additional reef repair sites receiving reef modules were treated in a similar manner. The remaining five sites of the fourteen total sites were treated by placement of a concrete pour, referred to as a "puddle pour," with limestone rock pressed into the surface for a natural appearance. These sites were not as severely damaged as those sites which were restored through establishment of artificial reef modules. The project was completed on July 22, 2002.

REFERENCES

[1] J.R. Clark, B. Causey, and J.A. Bohnsack, "Benefits from coral reef protection: Looe Key, Florida," *Coastal Zone '89, vol. 4, Proceedings of the Sixth Symposium on Coastal and Ocean Management*, ASCE, New York, 1989.